GEORGIA TECH RESEARCH INSTITUTE
NANOTECHNOLOGY LAB

Georgia Institute of Technology

Carbon Nanotube Tunable Microbattery

Philippe Lacasse
Georgia Tech Research Institute
Electro-Optics Systems Lab

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Georgia Tech Research Institute

EOSL Electro-Optical Systems Laboratory
Georgia Tech Research Institute

Introduction and Initial Plan

- Based on work by Madou & Wang at UC Irvine (see right).
- Believed we could get better results using CNTs as anodes and cathodes.
- Initial plan was very aggressive
- Project stalled:
  - Choosing the metal to serve as the interdigitated array material
  - Selecting the proper negative photoresist.
  - Both of these steps involve creating new protocol.

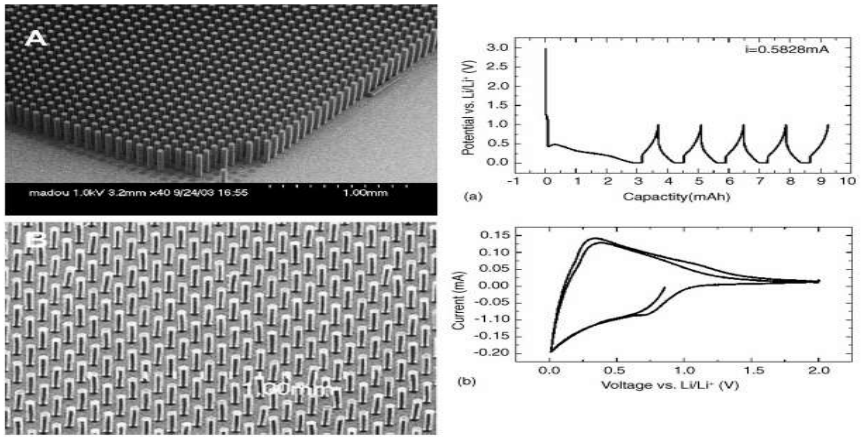
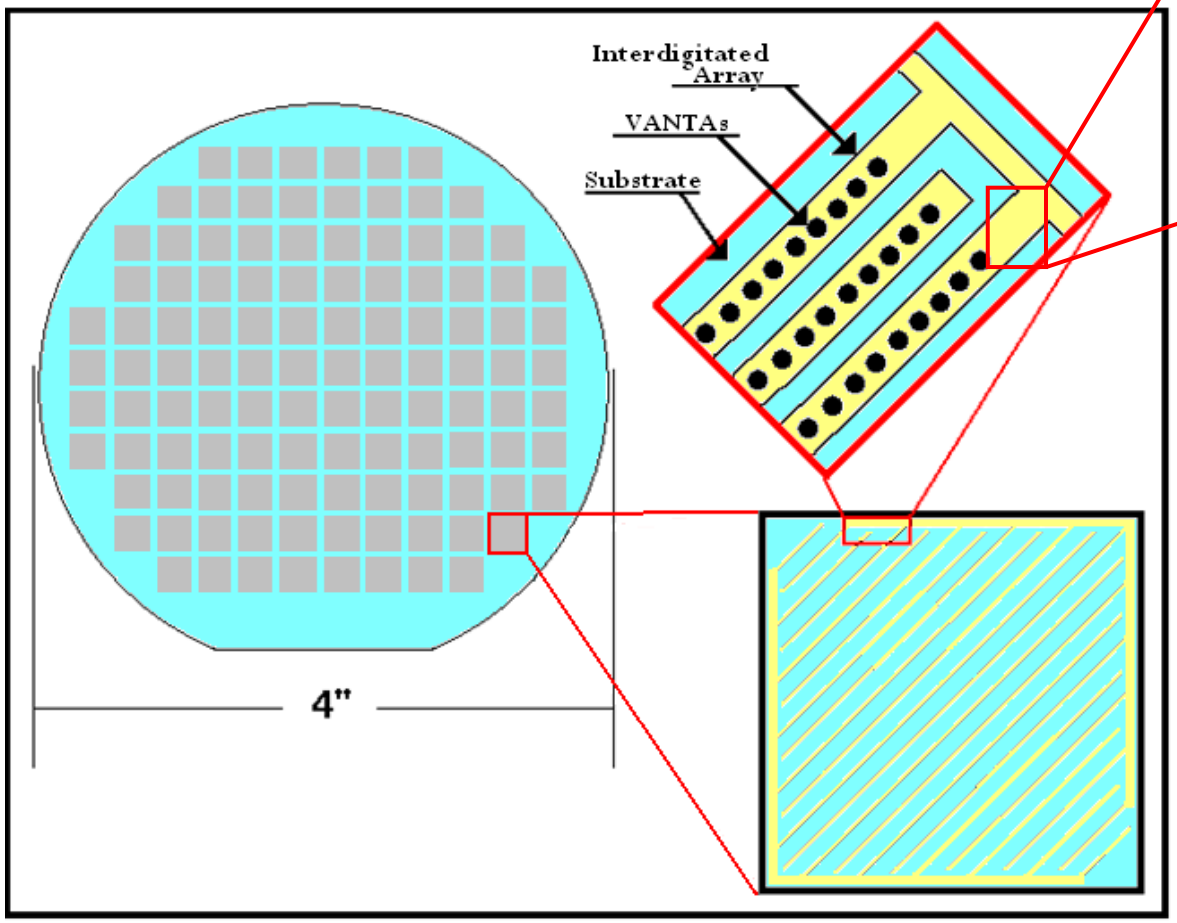
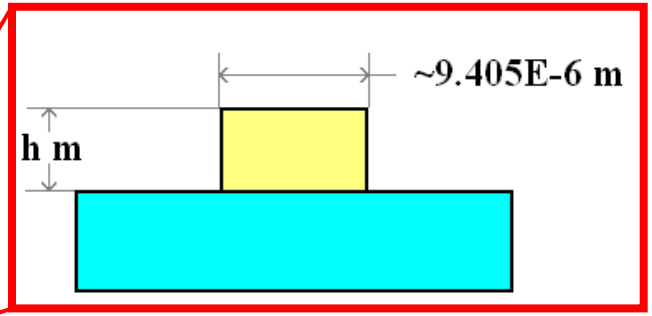


Fig. 1. Typical SEM images of (A) SU-8 post arrays (before pyrolysis) and (B) carbon post arrays (after pyrolysis). (a) Galvanostatic charge/discharge cycle behavior of patterned carbon arrays and (b) cyclic voltammetry of patterned carbon arrays.

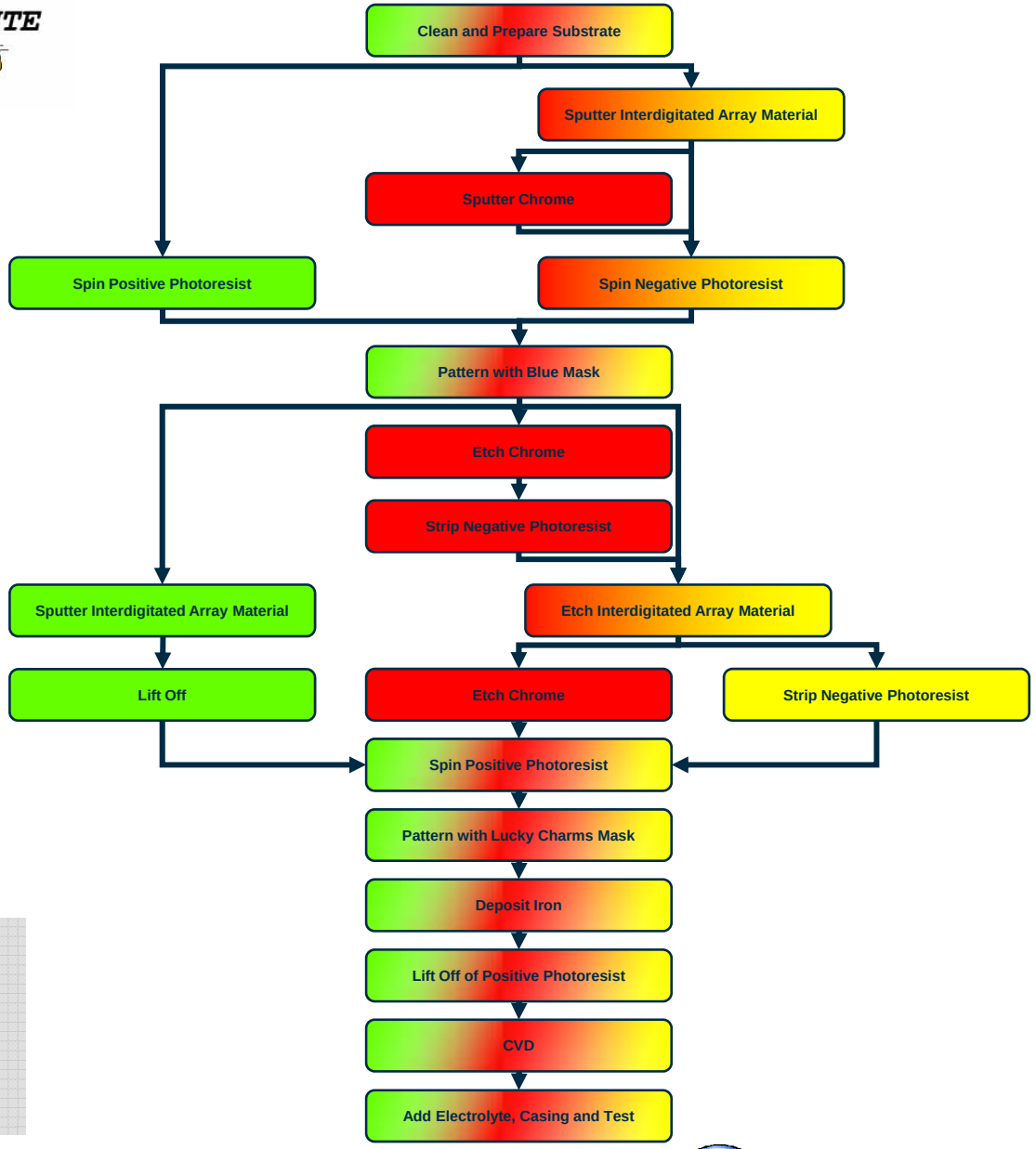




Microbattery Layout

- Channel Geometry
  - Parallel
  - Diagonal
  - Uniform width and length, varying height.
- Every other channel is connected to a site to be used for wire bonding.
- Differing lengths cause differing resistance profiles across the array.
- Calculated the resistance for short, middle and long digit to get good profile.

Fabrication Tree



Key:

Positive PR Method
Chrome Negative PR Method
Chromeless Negative PR Method

Comparison of Fabrication Processes

	Positive Photoresist Method	Chrome Negative Photoresist Method	Chromeless Negative Photoresist Method
	"Positive Method"	"Chrome Method"	"Chromeless Method"
Spin Photoresist	2	2	2
Pattern Photoresist	2	2	2
Lift Off/Stripping	2	2	2
Deposition/Sputter	2	3	2
Etching	0	3	1
CVD	1	1	1
Total Steps	9	13	10
Advantages	• Simplest method. • Fewest process steps. • Able to leverage lab experience.	• Most likely to work correctly. • Negative PR* can be remove without damaging the IA**. • Can use SU-8 Negative Photoresist that we already have.	• Least complicated of the two Negative PR* methods.
Disadvantages	• Positive PR* likely to bake in sputterer.	• Most complicated. • Lab has never used negative PR* before. • IA may use untested etchant. • Introduces extra etching steps.	• Negative PR* probably will damage IA** layer. • Lab has never used negative PR* before. • IA may use untested etchant.
Order of Preference	1	2	3

Step 1: Clean and Prepare Substrate

Positive Method

Cross-Section View

Overhead/Plan View

SUBSTANCE

- SILLICON & NATIVE SILLICA
- INTERDIGITATED ARRAY MATERIAL
- CHROME
- POSITIVE PHOTORESIST
- NEGATIVE PHOTORESIST
- IRON
- CARBON NANOTUBES
- ELECTROLYTE

Spin Positive Photoresist

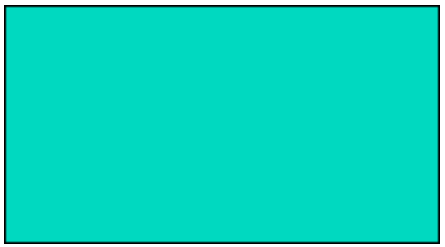
[Spinner]

Step 2: Spin Positive Photoresist

Positive Method

Cross-Section View

Overhead/Plan View



SUBSTANCE

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Pattern with Blue Mask

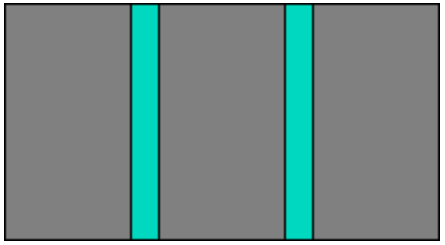
[Mask Aligner, Wet Bench]

Step 3: Pattern with Blue Mask

Positive Method

Cross-Section View

Overhead/Plan View



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Sputter Interdigitated Array Material

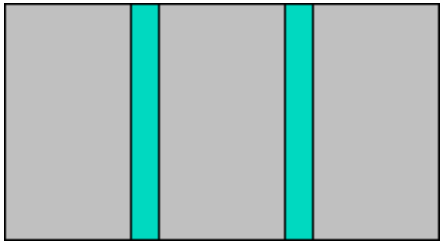
[DC Sputterer]

Step 4: Sputter Interdigitated Array Material

Positive Method

Cross-Section View

Overhead/Plan View



SUBSTANCE

- Silicon & Native Sillica
- Interdigitated Array Material
- Chrome
- Positive Photoresist
- Negative Photoresist
- Iron
- Carbon Nanotubes
- Electrolyte

Strip Positive Photoresist

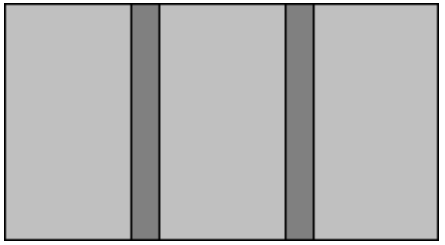
[Wet Bench]

Step 5: Strip Positive Photoresist

Positive Method

Cross-Section View

Overhead/Plan View



SUBSTANCE

- Silicon & Native Sillica
- Interdigitated Array Material
- Chrome
- Positive Photoresist
- Negative Photoresist
- Iron
- Carbon Nanotubes
- Electrolyte

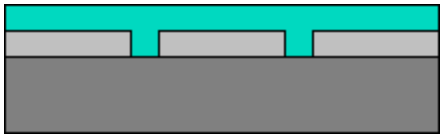
Spin Positive Photoresist

[Spinner]

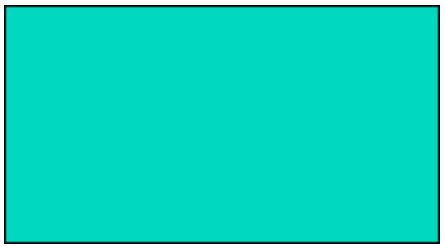
Step 6: Spin Positive Photoresist

Positive Method

Cross-Section View



Overhead/Plan View



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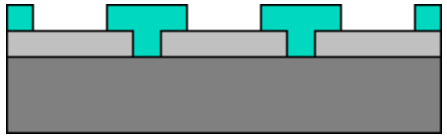
Pattern with Lucky Charms Mask

[Mask Aligner, Wet Bench]

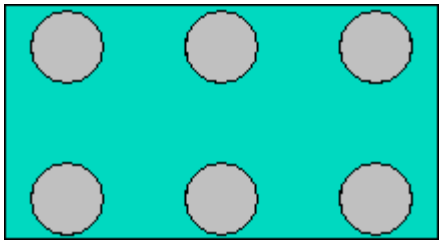
Step 7: Pattern with Lucky Charms Mask

Positive Method

Cross-Section View



Overhead/Plan View



SUBSTANCE

- Sillicon & Native Sillica
- Interdigitated Array Material
- Chrome
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- Electrolyte

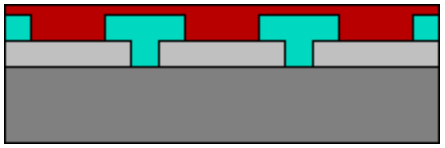
Deposition of Iron

[Denton Thermal Evaporator]

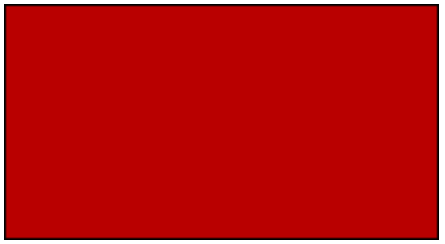
Step 8: Deposit Iron

Positive Method

Cross-Section View



Overhead/Plan View



SUBSTANCE

- Silicon & Native Sillica
- Interdigitated Array Material
- Chrome
- Positive Photoresist
- Negative Photoresist
- Iron
- Carbon Nanotubes
- Electrolyte

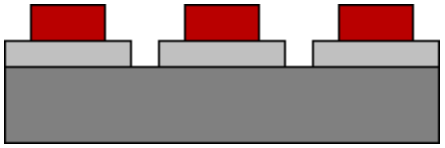
Lift Off of Positive Photoresist

[Wet Bench]

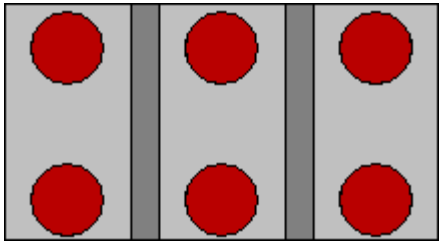
Step 9: Lift Off of Positive Photoresist

Positive Method

Cross-Section View



Overhead/Plan View



SUBSTANCE

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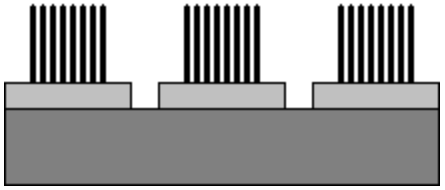
Dice and CVD

[__?__, First Nano Chemical Vapor Deposition Unit]

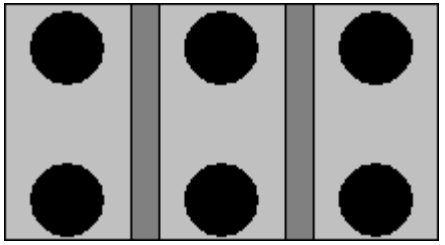
Step 10: Dice and CVD

Positive Method

Cross-Section View



Overhead/Plan View



SUBSTANCE

- Sillicon & Native Sillica
- Interdigitated Array Material
- Chrome
- Positive Photoresist
- Negative Photoresist
- Iron
- Carbon Nanotubes
- Electrolyte

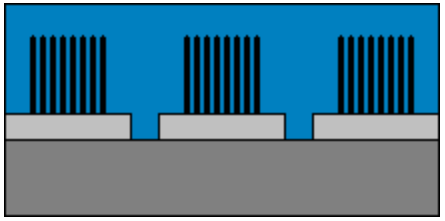
Add Electrolyte, Casing and Testing

[Wet Bench, Coin Cell Crimper, Electrical Testing Equipment]

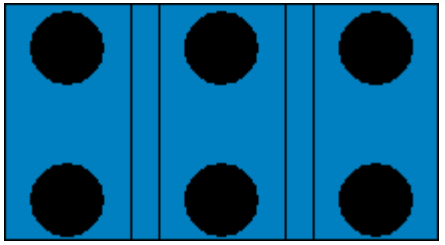
Step 11: Add Electrolyte, Casing and Testing

Positive Method

Cross-Section View



Overhead/Plan View



SUBSTANCE

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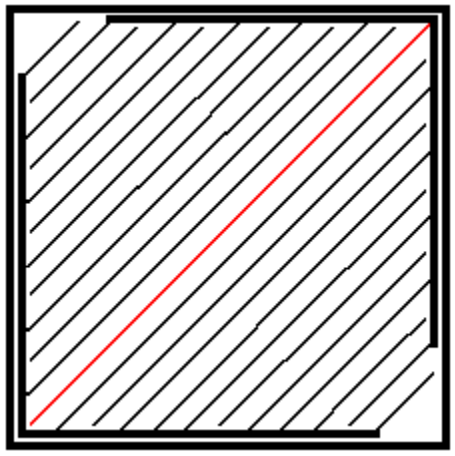
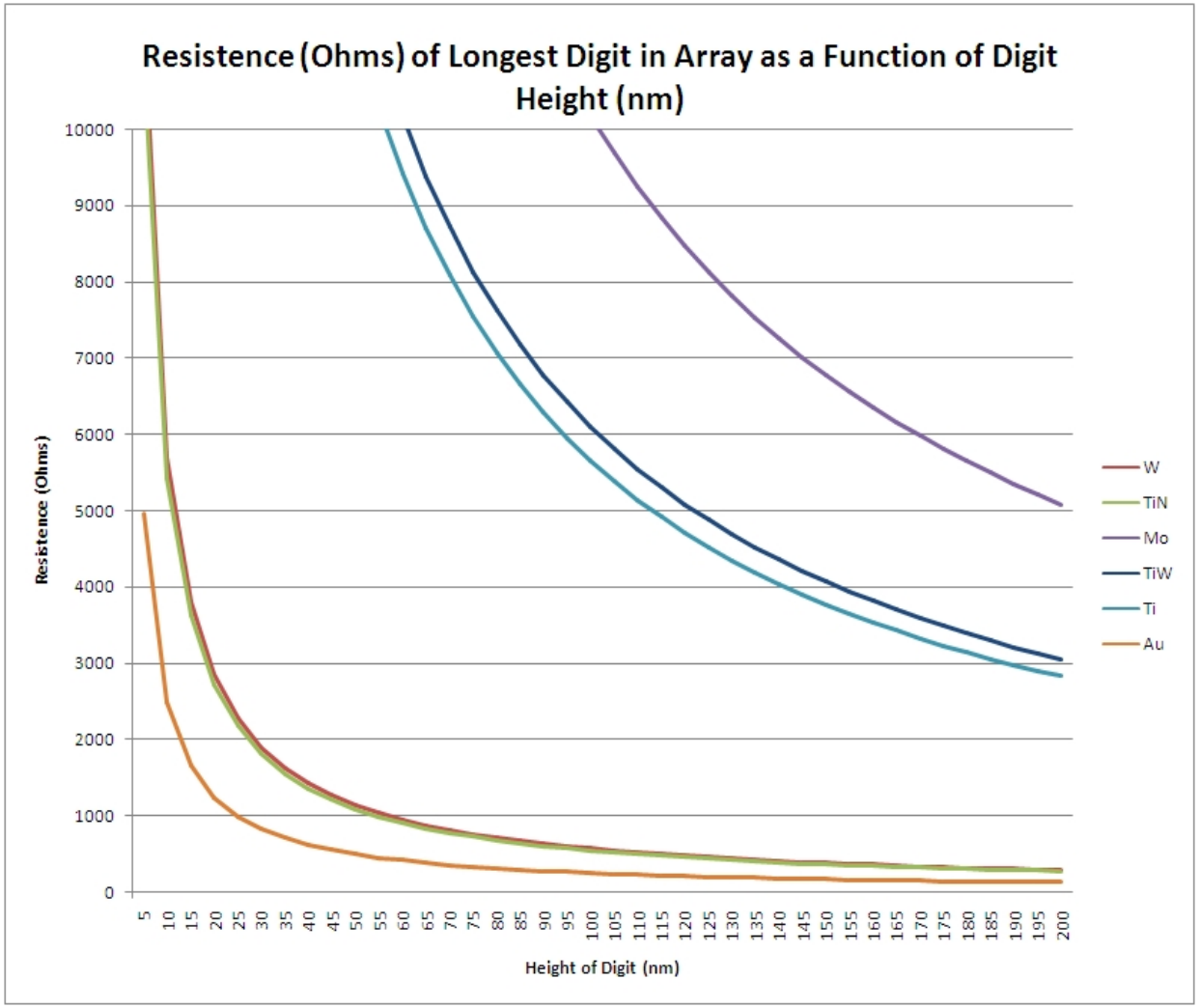
Longest Digit

- **Length of digit: 9563μm**

$$R = f(H) = \frac{\rho L}{W}\left(\frac{1}{H}\right)$$

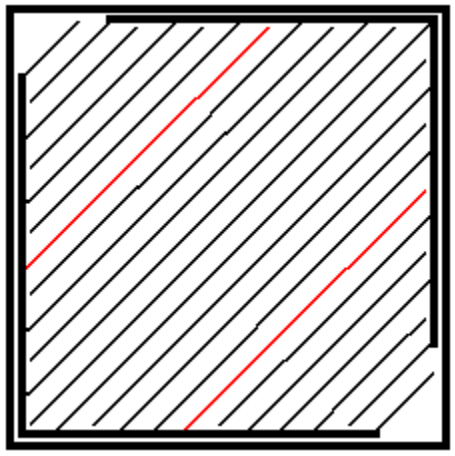
R	[=]	Ω	≡	Electrical Resistance
ρ	[=]	$\Omega \bullet m$	≡	Resistivity
L	[=]	m	≡	Length of Digit
W	[=]	m	≡	Width of Digit
H	[=]	m	≡	Height of Digit

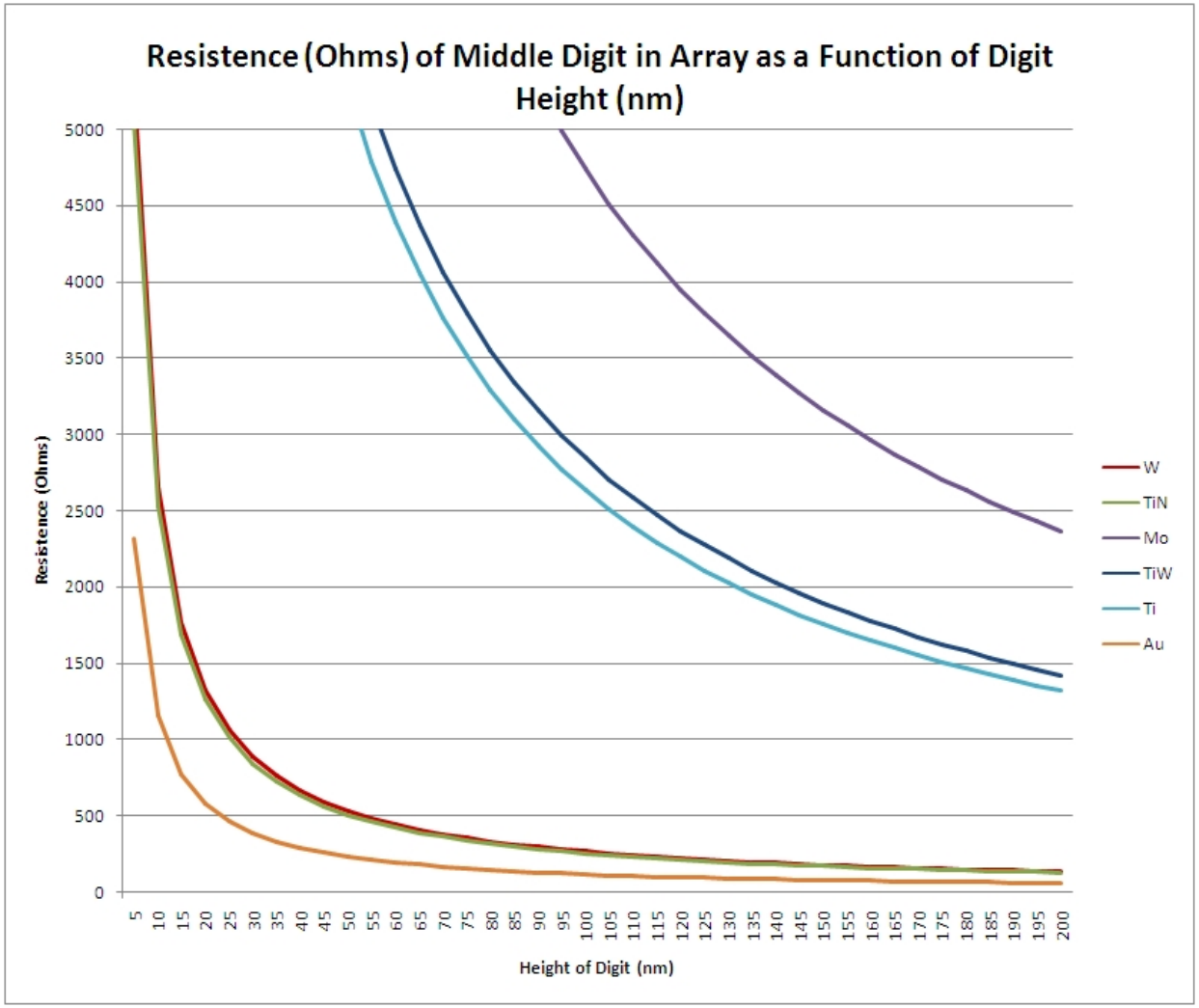




Middle Digit

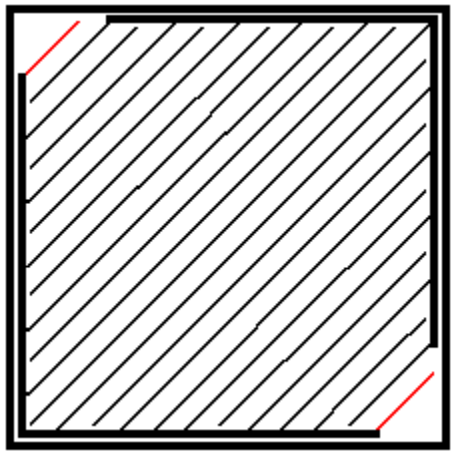
- Length of Digit: 4454.7718µm
- Mo can be ruled out as material because of its resistance.
- W and TiN are pretty much the same in resistance, as is TiW and Ti.

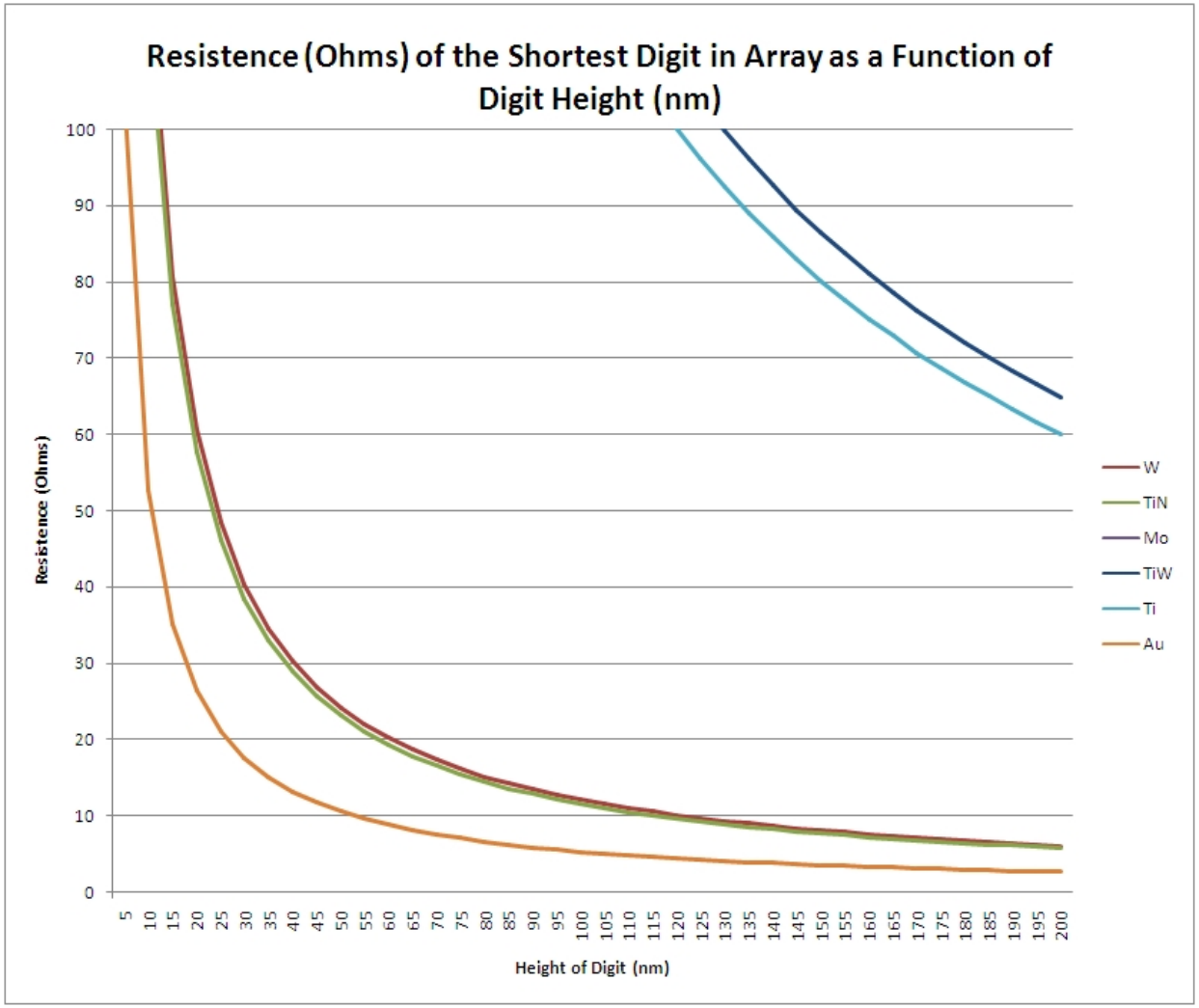




Short Digit

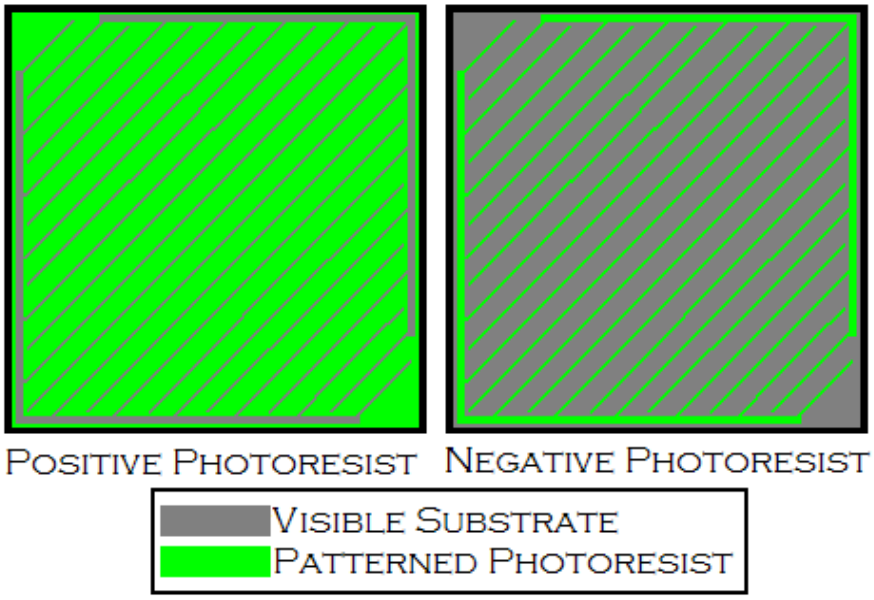
- Length of Digit: 203.3μm
- Au doesn't make good substrate for CNT growth.
- Chose TiW and TiN.
  - TiW is easy to work with in etching.
  - TiN has better resistance values.





Negative vs. Positive Photoresist

- The shadow mask we have is inverse of what we need.
- When exposed with positive photoresist (what we normally use), it develops the channels.
  - This is good for depositing the channels, but not for etching them.
  - We cannot put the positive photoresist in the sputterer to lay down the metal.
- Need to buy and develop procedure for negative photoresist.
- Develop procedure for stripping.



Future Decisions

- Wet etching? Plasma etching?
- Learn to align “Lucky Charms” mask with the “Blue” mask (through positive photoresist).
- Grow CNTs with AcUHYCNT820 (30 mins) recipe.
- Wire bonding.
- Use LabView and new electrical testing equipment to characterize the samples.